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Agricultural Memorandum No 434 Dr M Hough.

TRANSPIRATION FROM TALL CROPS

Agricultural Memorandum No 369 attempted to estimate the increase in transpiration of a tall crop relative to a short crop whose transpiration rate was assumed known. The short crop was taken to be grass 2 cm tall and its transpiration could be found by the methods in Technical Bulletin no 16. In this way it is possible to estimate water use by cereal crops during the summer and arrive at return to capacity dates for grain fields.

Transpiration

The Penman formula is

$$LE = \frac{\frac{\Delta}{\gamma} H + \frac{\rho Cp\ da}{\gamma\ r_a}}{\frac{\Delta}{\gamma} + (1 + \frac{r_s}{r_a})} \qquad (1)$$

The symbols are as in Ag. Mem. 369.

However, recently Thom (1972) has pointed out that since equation (1) is based on the assumption of equality between the transfer processes for heat, moisture and momentum, it is not correct and an alternative theory was given. If the difference in transfer process for momentum as compared with heat and moisture is taken into account Thom rewrites equation (1) as:

$$LE = \frac{\frac{\Delta}{\gamma} H + \frac{\rho Cp\ da}{\gamma\ r_H}}{\frac{\Delta}{\gamma} + (1 + \frac{r_{sT}}{r_H})} \qquad (2)$$

In equation (2) r_H is the resistance to the transfer of heat or moisture in the air, and r_{sT} is the bulk stomatal resistance to vapour transfer of the crop. Thom suggests that

$$r_H \geqslant r_a \text{ and } r_{sT} \leqslant r_s$$

where,

$$r_H(z) = \frac{1}{kU_*} \ln \left(\frac{z - d}{z_o B^{-1} \exp(-k)}\right) \qquad (3)$$

In equation (3) d is the zero plane displacement and B^{-1} is a nearly constant factor introduced to allow for the different transport properties of heat, moisture and momentum.

Similarly to Ag. Mem. 369 f is the ratio of the radiative and aerodynamic terms for transpiration from short grass ie.

$$f = \frac{\Delta}{\gamma} H / \frac{\rho Cp\ da}{\gamma\ r_{HS}}$$

The subscript S refers to the shorter (smoother) crop. Also if the subscript R refers to the taller (rougher) crop, then the ratio of transpirations for the two surfaces under the same weather is,

$$\frac{E_R}{E_S} = \frac{\left(f + \frac{da\ (\bar{z})_S}{da\ (\bar{z})_R} \quad \frac{r_H\ (\bar{z})_S}{r_H\ (\bar{z})_R}\right)\left(\frac{\Delta}{\gamma} + 1 + \frac{r_{ST}}{r_H\ (\bar{z})_S}\right)}{(1 + f)\left(\frac{\Delta}{\gamma} + 1 + \frac{r_{ST}}{r_H\ (\bar{z})_S} \quad \frac{r_H\ (\bar{z})_S}{r_H\ (\bar{z})_R}\right)} \qquad \text{——— (4)}$$

The stomatal resistance r_{ST} in equation (4) is assumed to be the same for both the tall and the short crop. The ratio $da\ (\bar{z})_S / da\ (\bar{z})_R$ is not known. To overcome this a similar method to that in Ag. Mem. 369 is used ie $\bar{z}$ is taken sufficiently large to ensure that the ratio is equal to 1.0. The value $\bar{z}$ = 100 m was chosen.

The ratio of the resistances is, from (3)

$$\frac{r_H\ (\bar{z})_S}{r_H\ (\bar{z})_R} = \frac{U_* R}{U_* S} \quad \frac{\ln\left(\frac{\bar{z} - d}{Z_{oS}\ B^{-1}\ \exp(-k)}\right)}{\ln\left(\frac{\bar{z} - d}{Z_{oR}\ B^{-1}\ \exp(-k)}\right)}$$

The ratio of friction velocities U_*R/U_*S is obtained from Monin and Zilitinkevich (1967) as in Ag. Mem. 369. This assumes a geostrophic wind equal to 5 m/sec.

For transpiration at the potential rate the criterion is $r_{ST} = 0$, rather than $r_S = 0$. Equation (4) becomes for potential transpiration:

$$\frac{E_R}{E_S} = \frac{\left(f + \frac{\ln(\bar{z} - d/\bar{z}_{oS}\ B^{-1}\ \exp(-k))}{\ln(\bar{z} - d/\bar{z}_{oR}\ B^{-1}\ \exp(-k))} \quad \frac{U_* R}{U_* S}\right)}{1 + f} \qquad \text{——— (5)}$$

where $\bar{z}$ = 100 m.

Variation of E_R/E_S

The graph shows E_R/E_S plotted against $\bar{z}_o$. The solid lines are for f = 2 and show that in general E_R/E_S increases as the roughness increases. However, E_R/E_S is decreased considerably by increases in the stomatal resistance. For r_{ST} = 2, E_R/E_S decreases as $\bar{z}_o$ increases which indicates that tall crops transpire less water than short grass under these conditions. For f = 3 (more sunshine or more humid atmosphere) the increase of E_R/E_S with $\bar{z}_o$ is less than for f = 2, but increasing leaf resistance reduces E_R/E_S as before. For r_{ST} = 2 the transpiration from a crop with $\bar{z}_o$ = 20 cm is about 90% that from short grass.

Assumptions made in the calculation of E_R/E_S

1. The short crop is assumed to have a z_o = 0.2 cm.

2. Geostrophic wind speed = 5 m/sec. The ratio U_{*R}/U_{*S} is read from the neutral curve (4b) as in Ag. Mem. 369.

3. Δ/γ is taken to be 1.86 which corresponds with a temperature of 62°F; f was taken as 2 or 3.

4. The bulk stomatal resistance r_{ST} was assumed to take the values: 0 (potential transpiration), 0.5, 1.0 and 2.0 sec cm^{-1}, and to be equal for tall and short crops.

5. The value of B^{-1} is 4 for all crops.

Criticisms of the Method

1. Assumes horizontal homogeneity of the underlying surface.

2. It relies on reading U_{*R}/U_{*S} from a graph.

3. Assumes an atmosphere in near neutral equilibrium. This is reasonable for f_0 = 2, but less so for f_0 = 3 and for large r_{ST} values.

4. Assumes that d_a above all crops is the same at z = 100 m.

Application to Maize

In June the plants have a $z_o \simeq$ 10 cm. If the leaf resistance is fairly small, about 0.5 sec cm^{-1}, then the maize would use about 19-24% more water than short grass. In July and August when z_o is about 15 or 20 cm maize would use about 24-30% more water than grass. If the leaf resistance were higher than 0.5 sec cm^{-1} due to dry soil during July/August than maize may only use 10-15% more water than grass.

For a short time immediately after rain when the leaves are wet, r_{ST} = 0 and transpiration from maize could be very high.

Water Balance

In view of the slightly smaller increases in transpiration compared with those suggested in Ag. Mem. 369, the maize water balance given in Ag. Mem. 374 was reconsidered. The June and July maximum potential transpirations seem about right, but the August value should be reduced from (potential + 30%) to (potential + 25%). Calculations show that this makes a negligible difference to the water balance except in a year when storage occurs in August. The main conclusion that maize fields return to capacity at about the same time as grass remains unchanged.

Any comments or criticisms should be sent direct to the author.

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REFERENCE

Thom, A S (1972) Momentum, mass and heat exchange of vegetation. Q.J.R. Met Soc, 98, pp 124-134.

RATIO OF TRANSPIRATION FOR LONG & SHORT CROP (E_R/E_S) AGAINST ROUGHNESS LENGTH. (THOM'S THEORY).